

Claims

1. A gallium nitride-based compound semiconductor device comprising:
 - a substrate;
 - a first superlattice layer which is formed above the substrate
 - 5 and in which an n-type AlGa_N layer and an n-type Ga_N layer are alternately layered;
 - a multiple quantum well layer which is formed above the first superlattice layer and in which a Ga_N-based quantum well layer and a Ga_N-based quantum barrier layer are alternately layered; and
 - 10 a second superlattice layer which is formed above the multiple quantum well layer and in which a p-type AlGa_N layer and a p-type Ga_N layer are alternately layered.
2. A gallium nitride-based compound semiconductor device according to Claim 1, wherein
 - 15 a buffer layer, a first Ga_N-based layer which is formed above the buffer layer, and an n-type Ga_N-based layer which is formed above the first Ga_N-based layer are provided between the substrate and the first superlattice layer;
 - 20 a second Ga_N-based layer is provided between the first superlattice layer and the multiple quantum well layer; and
 - a p-type Ga_N layer is provided above the second superlattice layer.
- 25 3. A gallium nitride-based compound semiconductor device according to Claim 2, wherein
 - the first Ga_N-based layer has a structure in which an Si₃N₄ layer is inserted in a Ga_N layer, and
 - the second Ga_N-based layer has an AlGa_N layer.

4. A gallium nitride-based compound semiconductor device according to Claim 1, wherein

5 a compositional ratio of Al in the GaN-based quantum barrier layer in the multiple quantum well layer is larger than compositional ratios of Al in the first superlattice layer and the second superlattice layer.

10 5. A gallium nitride-based compound semiconductor device according to Claim 1, wherein

each of compositional ratios of Al in the AlGa_N layers in the first superlattice layer and in the second superlattice layer is 5% or greater and 25% or smaller;

15 a compositional ratio of In in the InGa_N quantum well layer or the AlInGa_N quantum well layer in the multiple quantum well layer is 3% or greater and 20% or smaller;

a compositional ratio of Al in the AlGa_N quantum barrier layer or the AlInGa_N quantum barrier layer in the multiple quantum well layer is 1% or greater and 30% or smaller; and

20 a band gap of the quantum well layer is smaller than a band gap of the quantum barrier layer.

6. A gallium nitride-based compound semiconductor device according to Claim 1, wherein

25 each of thicknesses of the AlGa_N layer and the Ga_N layer in the first superlattice layer is 1 nm or greater and 10 nm or smaller;

a thickness of the quantum well layer in the multiple quantum well layer is 1 nm or greater and 5 nm or smaller;

a thickness of the quantum barrier layer in the multiple quantum

well layer is 2 nm or greater and 50 nm or smaller;

a thickness of the AlGa_N layer in the second superlattice layer is 0.5 nm or greater and 10 nm or smaller; and

a thickness of the Ga_N layer in the second super lattice layer
5 is 0.5 nm or greater and 5 nm or smaller.

7. A gallium nitride-based compound semiconductor device according to Claim 2, wherein

a thickness of the first Ga_N-based layer is 500 nm or greater
10 and 3000 nm or smaller;

a thickness of the n-type Ga_N-based layer is 500 nm or greater and 10000 nm or smaller;

each of thicknesses of the AlGa_N layer and the Ga_N layer in the first superlattice layer is 1 nm or greater and 10 nm or smaller;

15 a thickness of the second Ga_N-based layer is 5 nm or greater and 100 nm or smaller;

a thickness of the quantum well layer in the multiple quantum well layer is 1 nm or greater and 5 nm or smaller;

a thickness of the quantum barrier layer in the multiple quantum
20 well layer is 2 nm or greater and 50 nm or smaller;

a thickness of the AlGa_N layer in the second superlattice layer is 0.5 nm or greater and 10 nm or smaller;

a thickness of the Ga_N layer in the second superlattice layer is 0.5 nm or greater and 5 nm or smaller; and

25 a thickness of the p-type Ga_N-based layer is 5 nm or greater and 50 nm or smaller.

8. A gallium nitride-based compound semiconductor device according to Claim 1, wherein

each of thicknesses of the AlGa_N layer and the Ga_N layer in the first superlattice layer is 1.5 nm or greater and 5 nm or smaller;

a thickness of the quantum well layer in the multiple quantum well layer is 1 nm or greater and 2 nm or smaller;

5 a thickness of the quantum barrier layer in the multiple quantum well layer is 6 nm or greater and 20 nm or smaller;

a thickness of the AlGa_N layer in the second superlattice layer is 1 nm or greater and 6 nm or smaller, and

a thickness of the Ga_N layer in the second superlattice layer
10 is 0.5 nm or greater and 3 nm or smaller.

9. A gallium nitride-based compound semiconductor device according to Claim 2, wherein

a thickness of the first Ga_N-based layer is 1500 nm or greater
15 and 3000 nm or smaller;

a thickness of the n-type Ga_N-based layer is 1000 nm or greater and 2000 nm or smaller;

each of thicknesses of the AlGa_N layer and the Ga_N layer in the first superlattice layer is 1.5 nm or greater and 5 nm or smaller;

20 a thickness of the second Ga_N-based layer is 20 nm or greater and 40 nm or smaller;

a thickness of the quantum well layer in the multiple quantum well layer is 1 nm or greater and 2 nm or smaller;

a thickness of the quantum barrier layer in the multiple quantum
25 well layer is 6 nm or greater and 20 nm or smaller;

a thickness of the AlGa_N layer in the second superlattice layer is 1 nm or greater and 6 nm or smaller;

a thickness of the Ga_N layer in the second superlattice layer is 0.5 nm or greater and 3 nm or smaller; and

a thickness of the p-type GaN-based layer is 10 nm or greater and 40 nm or smaller.

10. A gallium nitride-based compound semiconductor device
5 comprising:

a substrate;

an n-type AlGa_N layer which is formed above the substrate;

a multiple quantum well layer which is formed above the n-type AlGa_N layer and in which a GaN-based quantum well layer and a GaN-based
10 quantum barrier layer are alternately layered; and

a p-type AlGa_N layer which is formed above the multiple quantum well layer.

11. A gallium nitride-based compound semiconductor device according
15 to Claim 10, wherein

a buffer layer, a first GaN-based layer which is formed above the buffer layer, and an n-type GaN-based layer which is formed above the first GaN-based layer are provided between the substrate and the n-type AlGa_N layer;

20 a second GaN-based layer is provided between the n-type AlGa_N layer and the multiple quantum well layer; and

a p-type GaN-based layer is provided above the p-type AlGa_N layer.

25 12. A gallium nitride-based compound semiconductor device according to Claim 10, wherein

a compositional ratio of Al in the GaN-based quantum barrier layer in the multiple quantum well layer is larger than compositional ratios of Al in the n-type AlGa_N layer and the p-type AlGa_N layer.

13. A gallium nitride-based compound semiconductor device according to Claim 10, wherein

each of compositional ratios of Al in the n-type AlGa_N layer
5 and in the p-type AlGa_N layer is 5% or greater and 25% or smaller;

a compositional ratio of In in the InGa_N quantum well layer
or the AlInGa_N quantum well layer in the multiple quantum well layer
is 3% or greater and 20% or smaller;

a compositional ratio of Al in the AlInGa_N quantum barrier
10 layer or the AlGa_N quantum barrier layer in the multiple quantum
well layer is 1% or greater and 30% or smaller, and

a band gap of the quantum well layer is smaller than a band
gap of the quantum barrier layer.

15 14. A gallium nitride-based compound semiconductor device according
to Claim 10, wherein

a thickness of the n-type AlGa_N layer is 50 nm or greater and
500 nm or smaller;

a thickness of the quantum well layer in the multiple quantum
20 well layer is 1 nm or greater and 5 nm or smaller;

a thickness of the quantum barrier layer in the multiple quantum
well layer is 2 nm or greater and 50 nm or smaller; and

a thickness of the p-type AlGa_N layer is 50 nm or greater and
500 nm or smaller.

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15. A gallium nitride-based compound semiconductor device according
to Claim 11, wherein

a thickness of the first Ga_N-based layer is 500 nm or greater
and 3000 nm or smaller;

a thickness of the n-type GaN-based layer is 500 nm or greater and 10000 nm or smaller;

a thickness of the n-type AlGaIn layer is 50 nm or greater and 500 nm or smaller;

5 a thickness of the second GaN-based layer is 5 nm or greater and 100 nm or smaller;

a thickness of the quantum well layer in the multiple quantum well layer is 1 nm or greater and 5 nm or smaller;

10 a thickness of the quantum barrier layer in the multiple quantum well layer is 2 nm or greater and 50 nm or smaller;

a thickness of the p-type AlGaIn layer is 50 nm or greater and 500 nm or smaller; and

a thickness of the p-type GaN-based layer is 5 nm or greater and 50 nm or smaller.

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16. A gallium nitride-based compound semiconductor device according to Claim 10, wherein

a thickness of the n-type AlGaIn layer is 70 nm or greater and 300 nm or smaller;

20 a thickness of the quantum well layer in the multiple quantum well layer is 1 nm or greater and 2 nm or smaller;

a thickness of the quantum barrier layer in the multiple quantum well layer is 6 nm or greater and 20 nm or smaller; and

25 a thickness of the p-type AlGaIn layer is 70 nm or greater and 200 nm or smaller.

17. A gallium nitride-based compound semiconductor device according to Claim 11, wherein

a thickness of the first GaN-based layer is 1500 nm or greater

and 3000 nm or smaller;

a thickness of the n-type GaN-based layer is 1000 nm or greater and 2000 nm or smaller;

a thickness of the n-type AlGaIn layer is 70 nm or greater and
5 300 nm or smaller;

a thickness of the second GaN-based layer is 20 nm or greater and 40 nm or smaller;

a thickness of the quantum well layer in the multiple quantum well layer is 1 nm or greater and 2 nm or smaller;

10 a thickness of the quantum barrier layer in the multiple quantum well layer is 6 nm or greater and 20 nm or smaller;

a thickness of the p-type AlGaIn layer is 70 nm or greater and 200 nm or smaller; and

a thickness of the p-type GaN-based layer is 10 nm or greater
15 and 40 nm or smaller.

18. A method for manufacturing a gallium nitride-based compound semiconductor device according to Claim 2 through MOCVD, wherein
the buffer layer is formed on the substrate at a temperature
20 of 450 °C or higher and 600 °C or lower;

the first GaN-based layer, the n-type GaN-based layer, and the first superlattice layer are sequentially formed on the buffer layer at a temperature of 1050 °C or higher and 1100 °C or lower;

the second GaN-based layer and the multiple quantum well layer
25 are sequentially formed on the first superlattice layer at a temperature of 800 °C or higher and 900 °C or lower; and

the second superlattice layer and the p-type GaN-based layer are sequentially formed on the multiple quantum well layer at a temperature of 950 °C or higher and 1025 °C or lower.

19. A method for manufacturing a gallium nitride-based compound semiconductor device according to Claim 11 through MOCVD, wherein

the buffer layer is formed on the substrate at a temperature
5 of 450 °C or higher and 600 °C or lower;

the first GaN-based layer, the n-type GaN-based layer, and
the n-type AlGaIn layer are sequentially formed on the buffer layer
at a temperature of 1050 °C or higher and 1100 °C or lower;

the second GaN-based layer and the multiple quantum well layer
10 are sequentially formed on the n-type AlGaIn layer at a temperature
of 800 °C or higher and 900 °C or lower; and

the p-type AlGaIn layer and the p-type GaN-based layer are
sequentially formed on the multiple quantum well layer at a
temperature of 950 °C or higher and 1025 °C or lower.

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20. A gallium nitride-based compound semiconductor device according
to any one of Claims 2 through 11, further comprising:

an n electrode which is connected to the n-type GaN-based layer;

a p electrode which is connected to the p-type GaN-based layer;

20 and

a power supply which applies a voltage between the n electrode
and the p electrode.

21. A device which uses a gallium nitride-based compound
25 semiconductor device according to Claim 20 as a light source and
irradiates light having a wavelength of 400 nm or shorter.